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Equatorial Upwelling in the Central Indian Ocean Estimated from Moored ADCP Array

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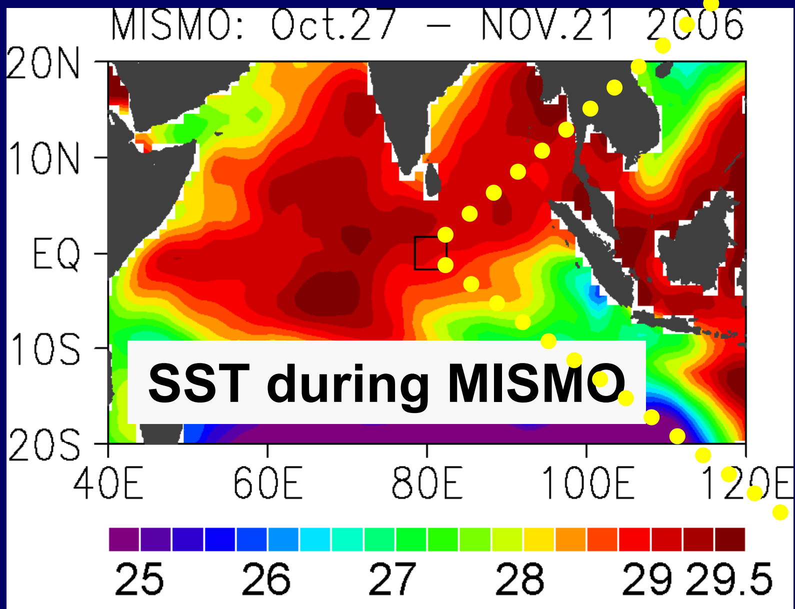
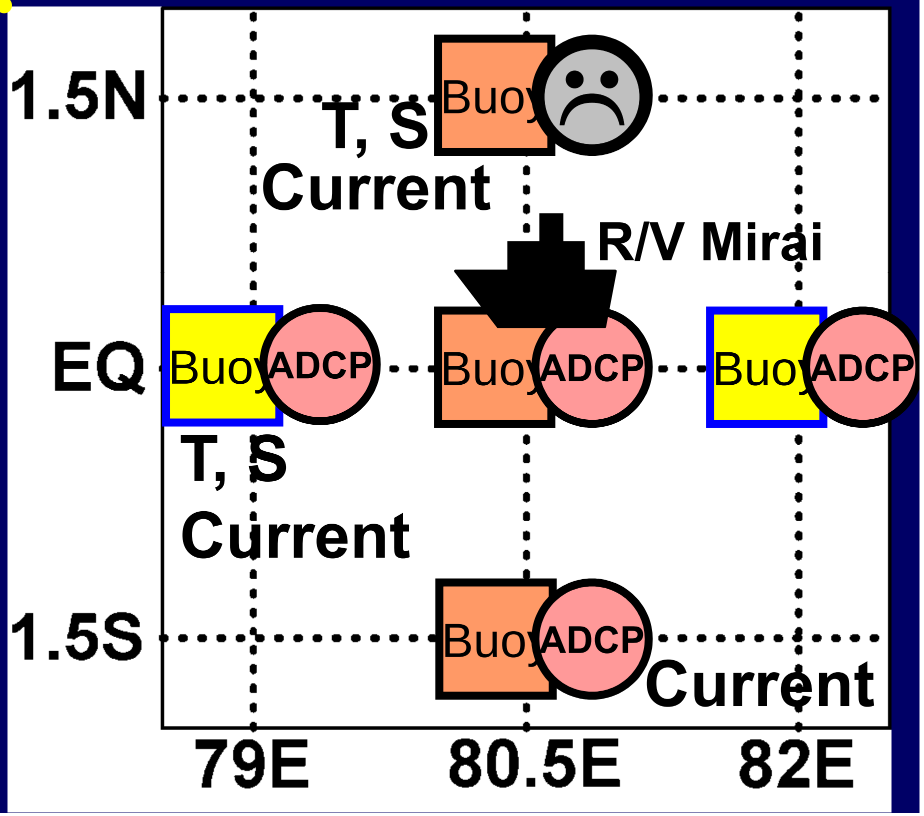
Outline

- **Part I:**
  - **Introduction of Ocean Observation during MISMO**
  - **A Review of Ocean Condition Observed in MISMO in Oct-Nov 2006**
- **Part II:**
  - **Equatorial Upwelling Estimated by the Ocean Current Data (ADCPs)**

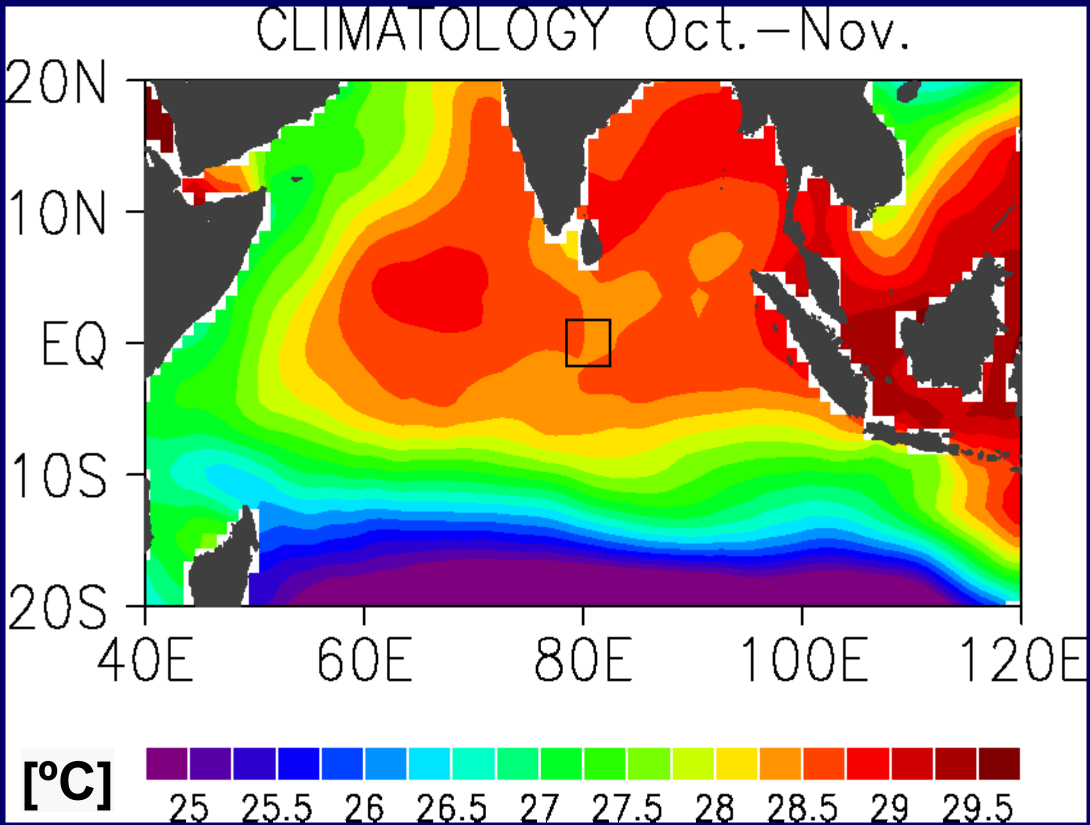
Ocean Observation

- Ocean Intensive Observation during "**MISMO**"
  - Temperature, Salinity, Current, and Flux (Masumoto et al. 2008 GRL)
  - m-TRITON Buoy & ADCP Array
  - Useful data for Short-term Ocean-Atmosphere Interaction



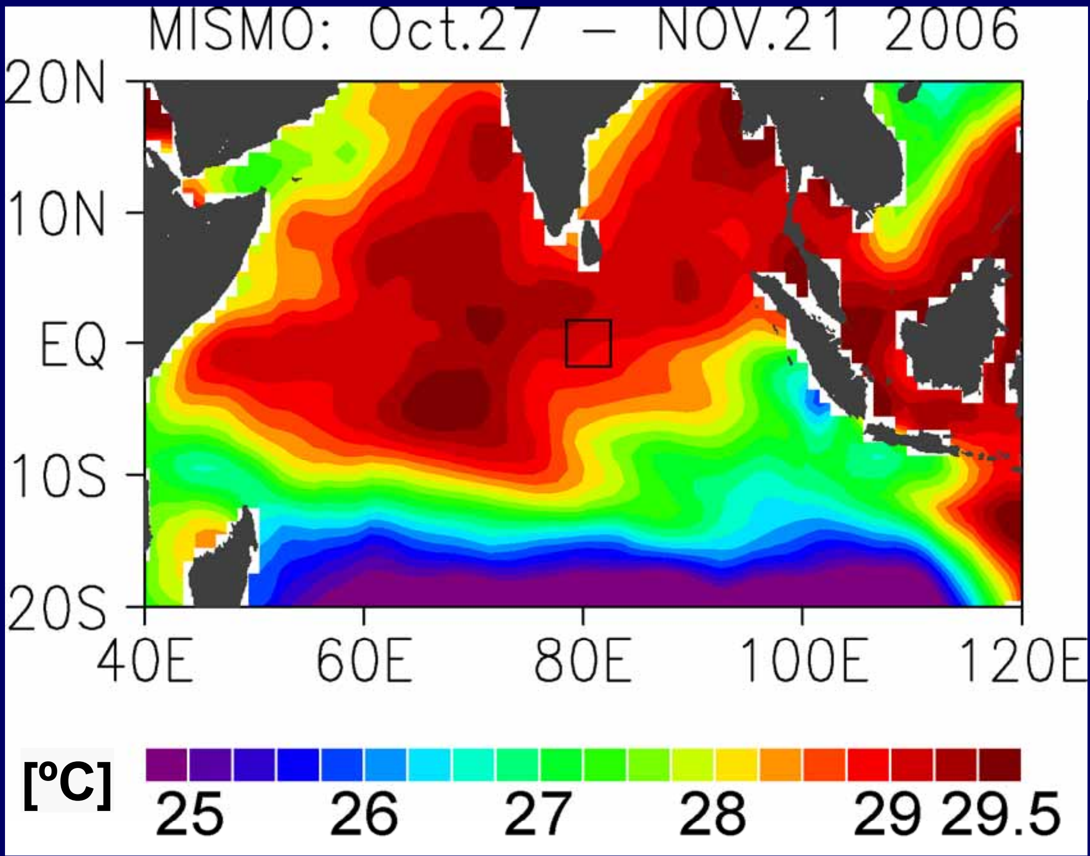


Background: Indian Ocean Dipole

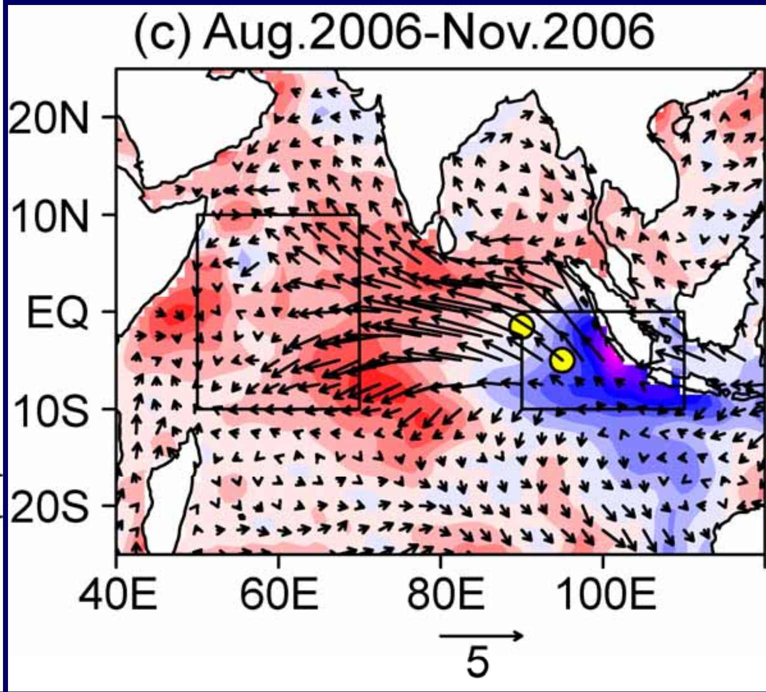


- Climatology in Oct-Nov
- No SST Gradient
- EQ Westerly Wind

Background: Indian Ocean Dipole



● **MISMO Period**

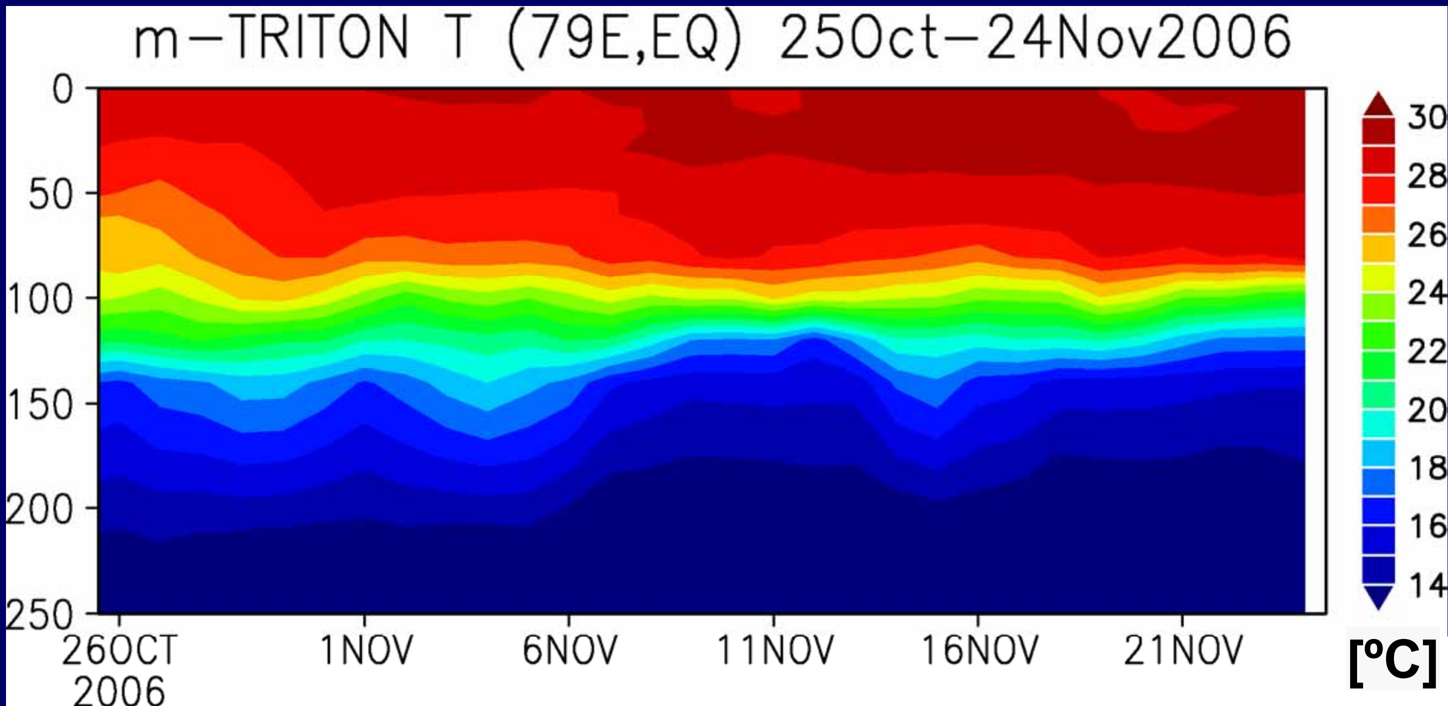


↑SST & Wind Anomaly

- **Cooler SST**
- **Large SST Gradient in the East**
- **Reversal of Climatological Wind (Westerly → Easterly Wind)**

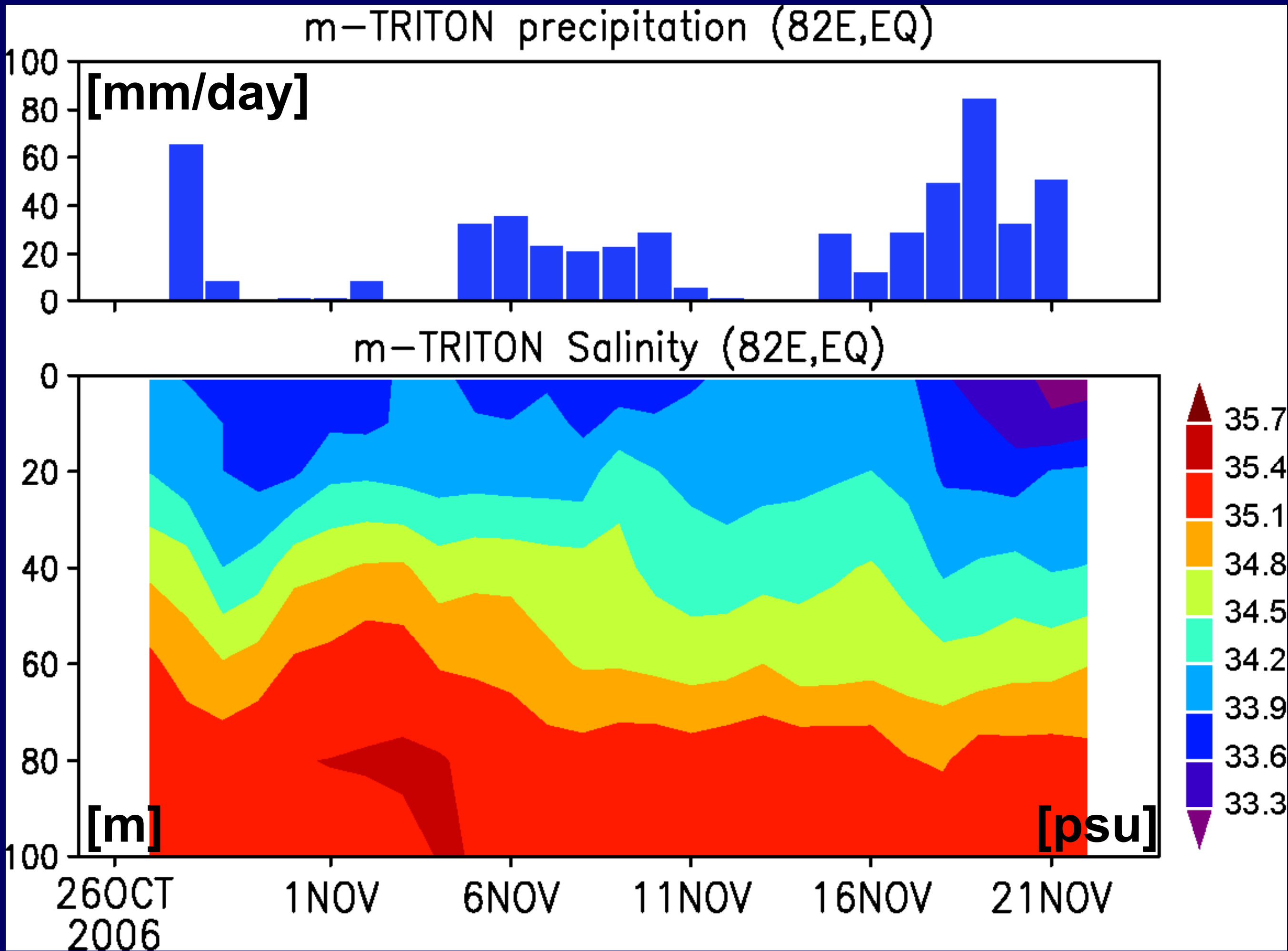
Temperature (79E, EQ)

- Surface Layer: Warming up to > 29ºC
- Deeper Layer: Cooling in the bottom of Thermocline
  - Existence of Upwelling?
- Tightening of the Thermocline

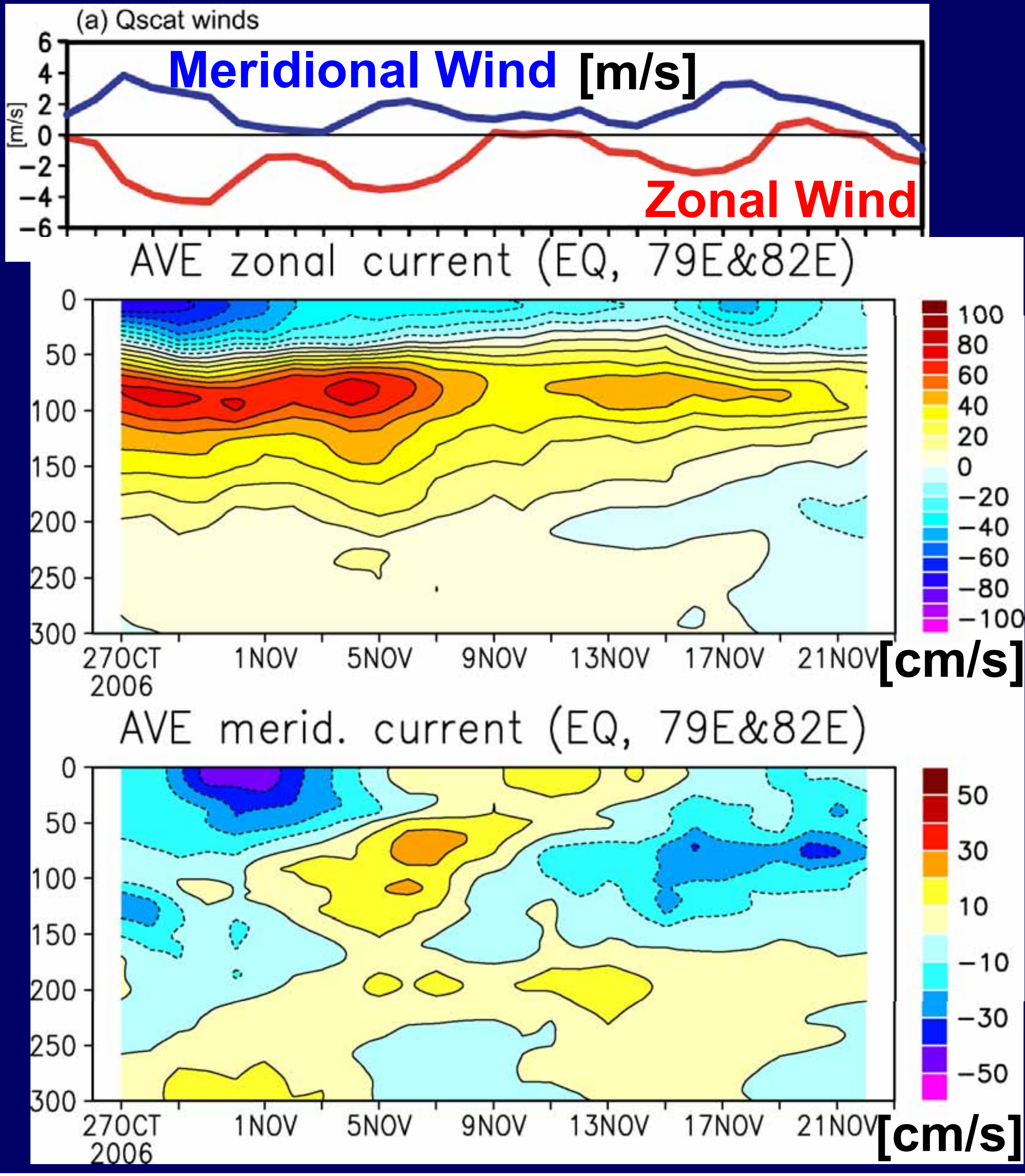


Salinity & Precipitation (82E, EQ)

- **Low Salinity Water in the Upper Layer**
  - **Consistent with Precipitation**
- **High Salinity Water in the Thermocline Depth**



Zonal & Meridional Current



ADCP & m-TRITON data

- Akima Spline Method

Zonal Current

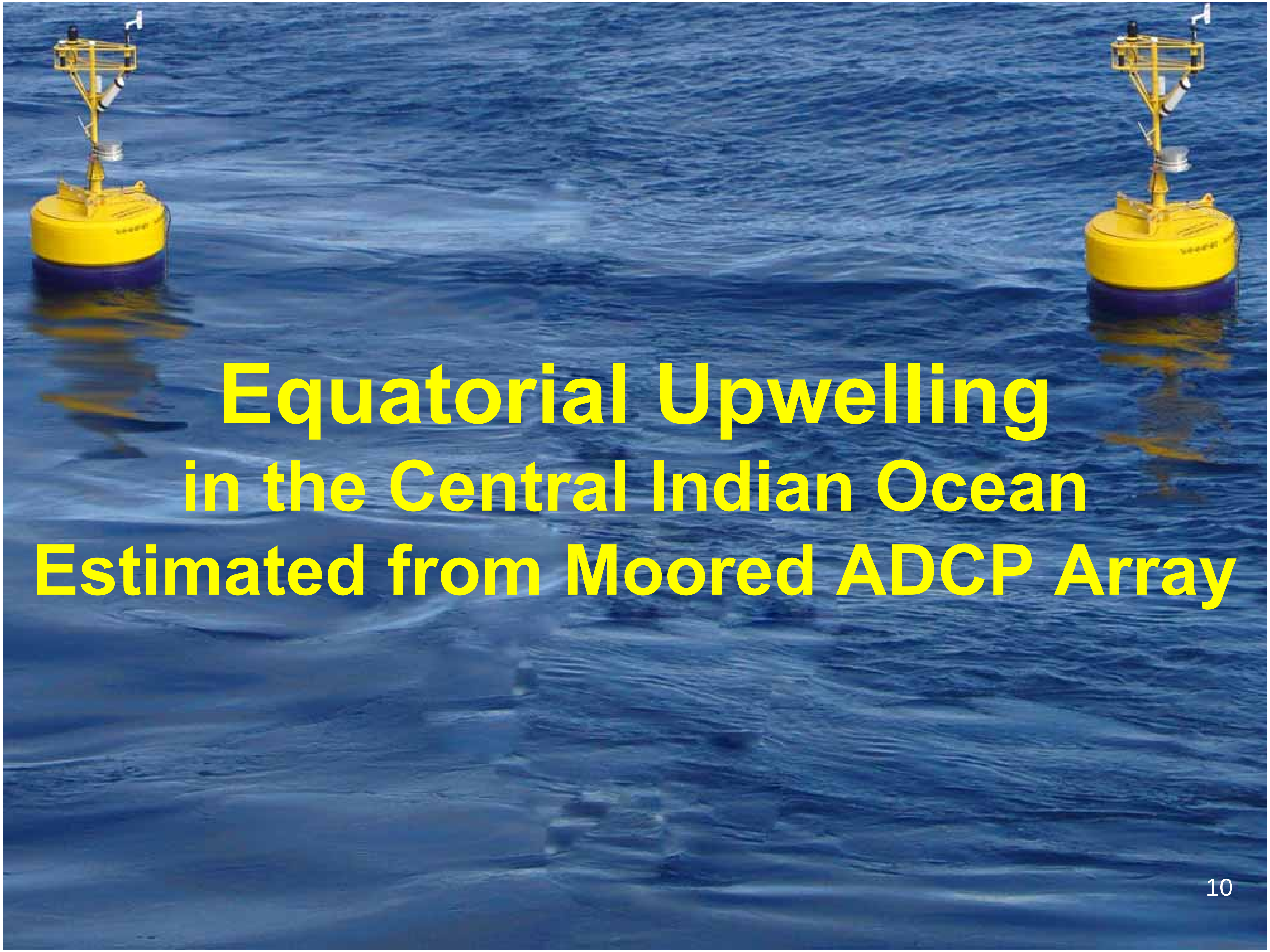
- Upper: Westward
- Subsurface: Eastward (≠Indian Ocean Clim.)
- Indian Ocean Dipole

Meridional Current

- 14-20 day period →
- EQ Mixed Rossby Gravity Wave? (Masumoto et al. 2005)

Summary of Part I

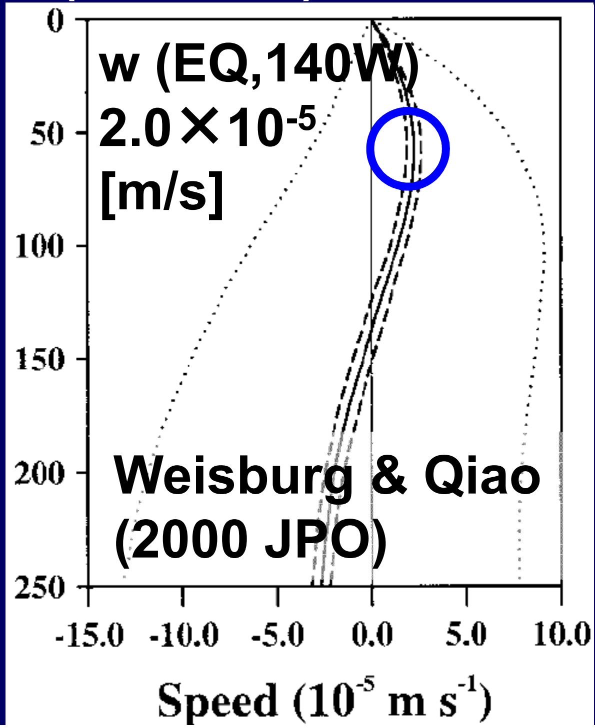
- MISMO ocean observations reveal the unique conditions in the central equatorial Indian Ocean during the 2006 Indian Ocean Dipole.
- New findings are
  - Tightening of the thermocline with warming of the surface layer and cooling of the layer below the thermocline;
  - Large vertical salinity gradient, with association with the precipitation at the surface;
  - Surface westward and subsurface eastward current, and large vertical shear of the zonal currents above the thermocline; and
  - Short-term variability in the meridional current in the upper 150m depth.



Equatorial Upwelling
in the Central Indian Ocean
Estimated from Moored ADCP Array

Background: EQ Vertical Velocity

- EQ upwelling is an important element in the EQ ocean circulation
  - Influence SST variation (→ Climate)
- Order of Vertical Velocity (W) is ～10^{-5} [m/s]
  - Estimate of "w" in the Pacific (Ocean Current Array)
  - East: Halpern et al. (1989JGR); Meinen et al. (2001JPO)
  - West: Helber & Weiseberg (2001JGR)
  - Mean Upwelling: ~ 2.0×10^{-5} [m/s]
- No Observation in the IO
- MISMO Observation
  - Observation of Horizontal Current by Three or More ADCPs
  - Estimate of "w" by Horizontal Conv./Div.

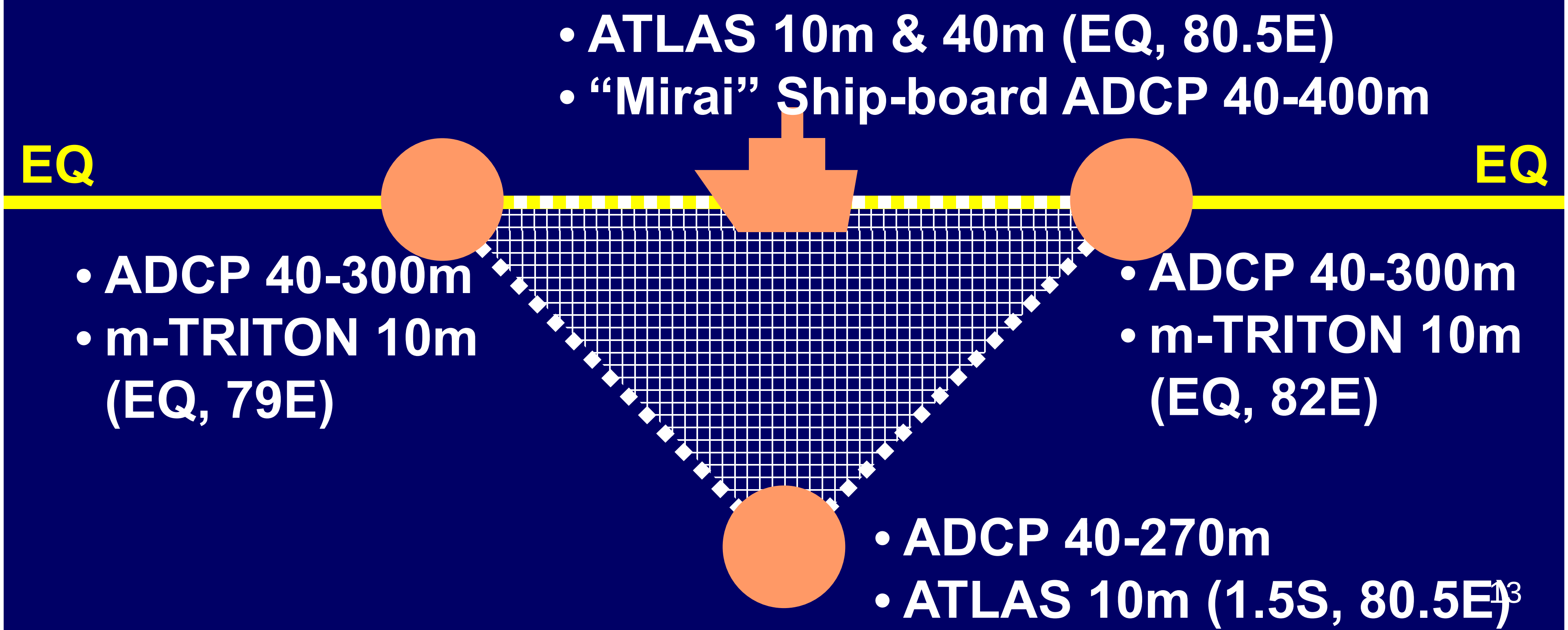


Objective

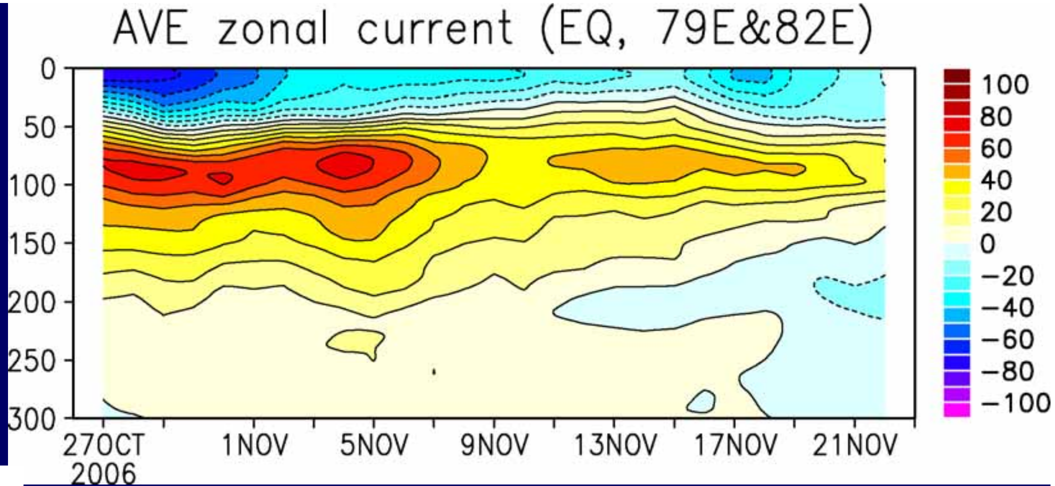
- **Big Goal:**
  Understanding 3-Dimensional Circulation in the Equatorial Indian Ocean
- **In this Study:**
  Estimate of Vertical Velocity "w" Using the ADCP array during MISMO
- **Content**
  - **Data & Method for Estimate of "w"**
  - **Result and Discussion**

Data & Method

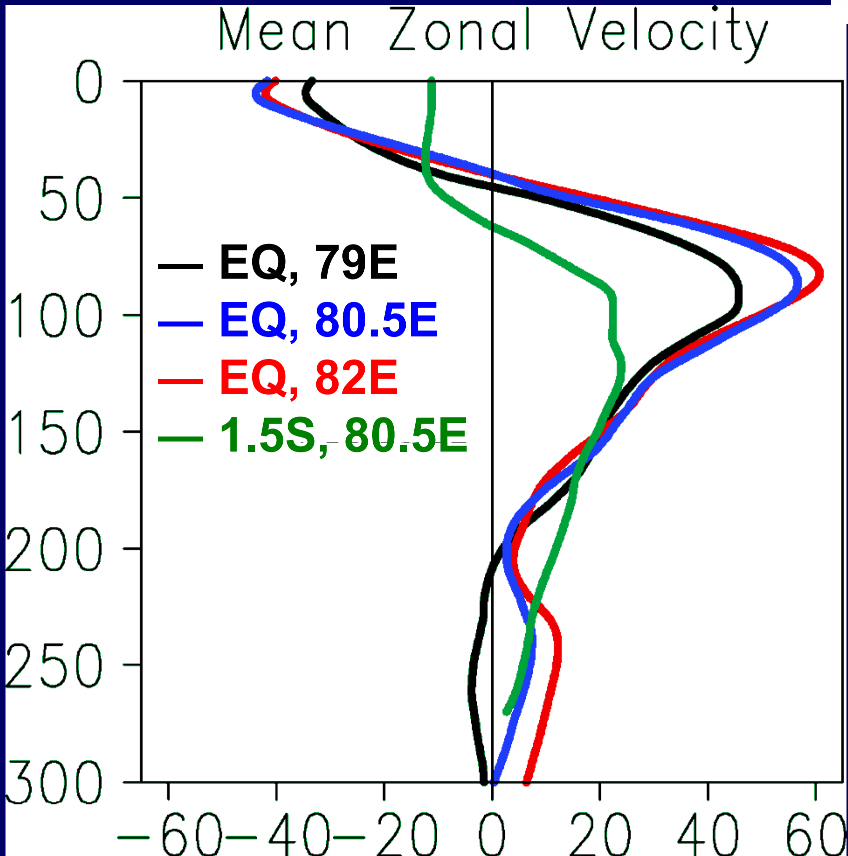
1. Merge “Buoy 10m data” & “ADCP 40-270m” Together
2. Interpolate Every 1m (0m~) by the Akima Spline Method
3. Calculate Conv./Div. in the Triangle Region, and Integrate Vertically Applying the Continuity Equation



Zonal Current

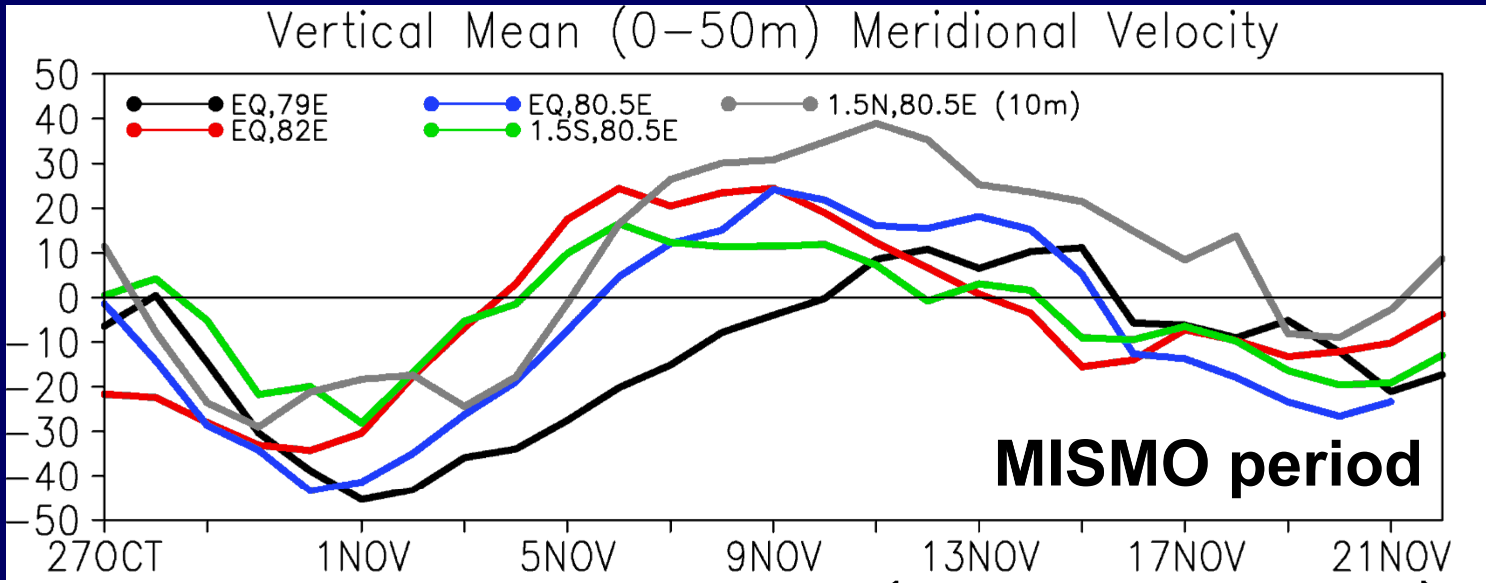


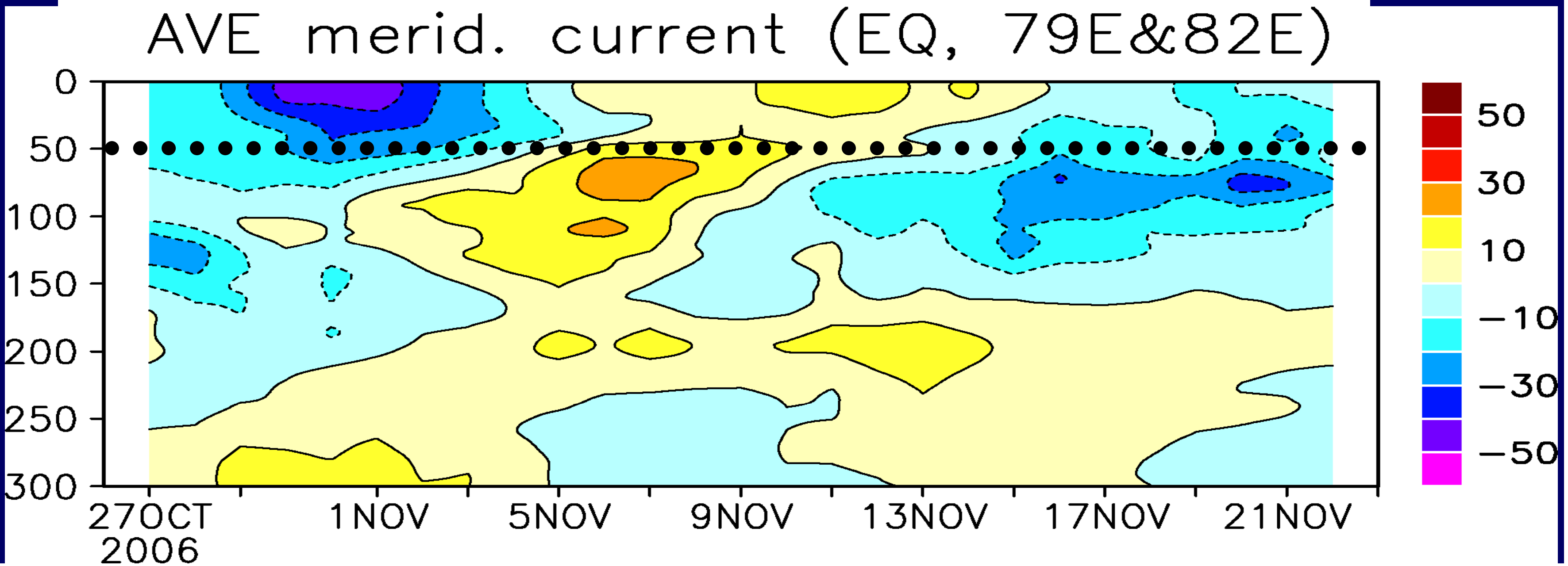
↓Mean Zonal Velocty



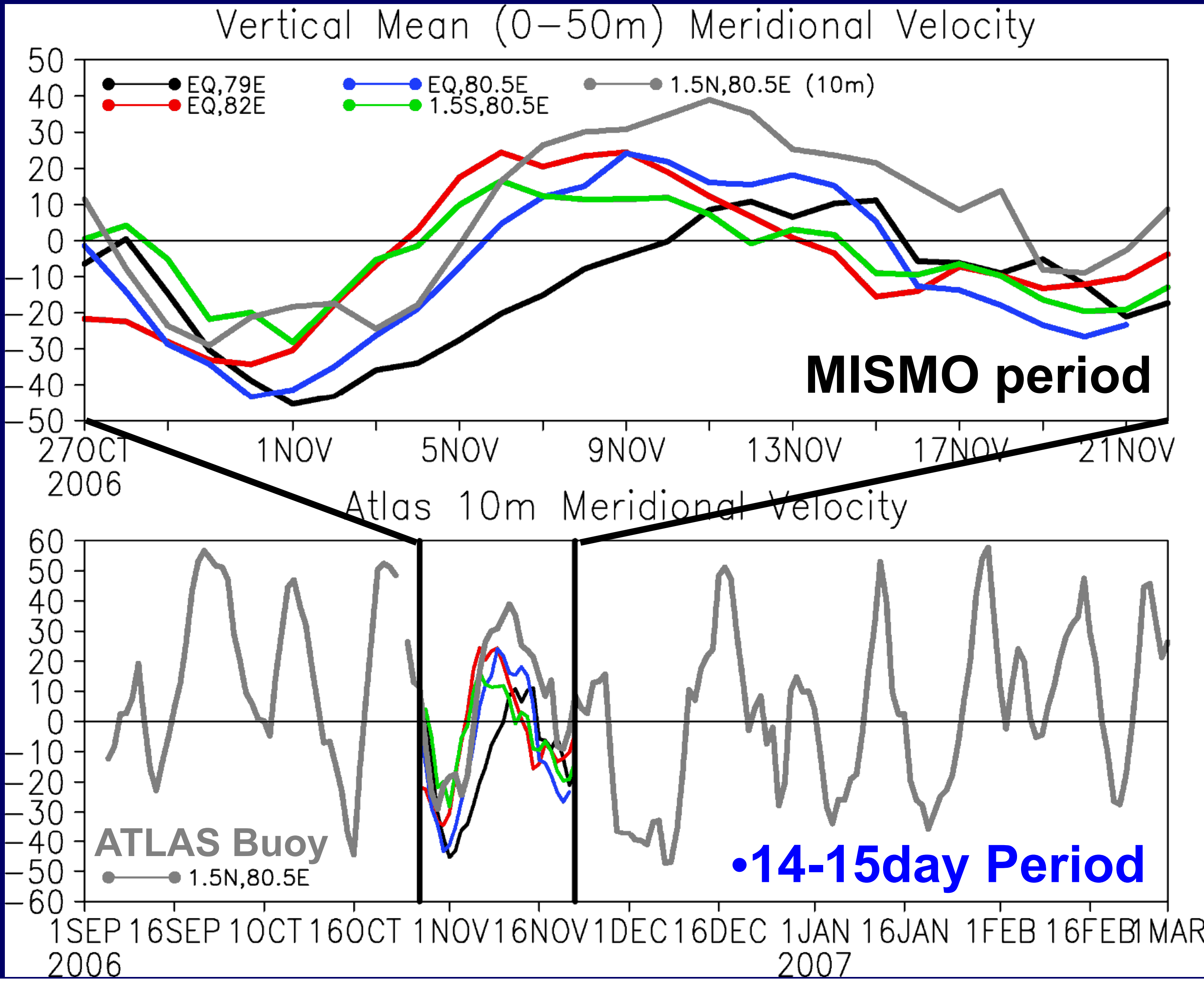
- Opposite Direction of Surface & Subsurface Current
- Acceleration of Eastward Current
- Weaker Current off of EQ

Meridional Current (0–50m)





Meridional Current (14-15day period)

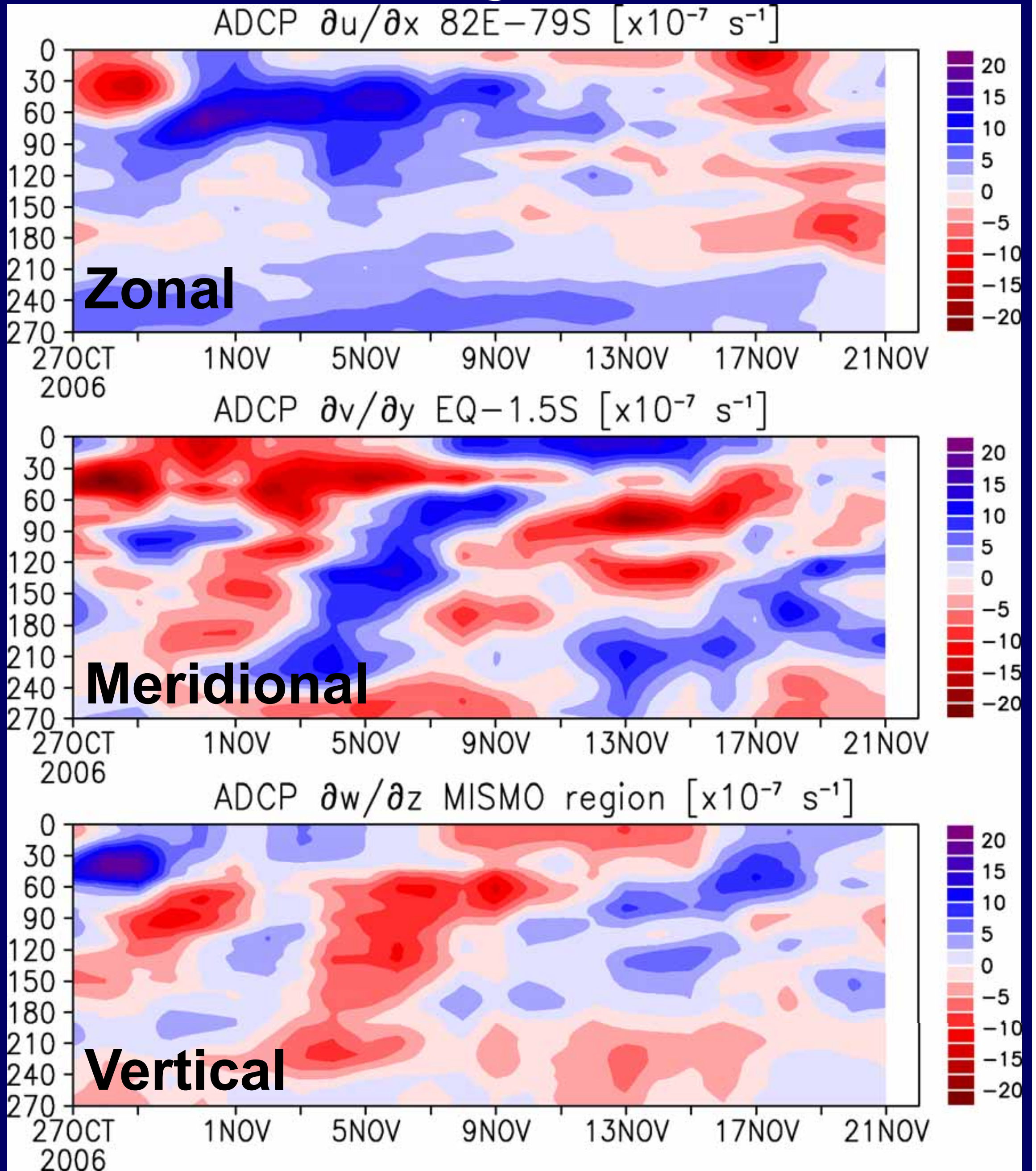


Conv/Div of Currents: ∂u/∂x,∂v/∂y, ∂w/∂z

- Positive (Blue): Div.
- Negative (Red): Conv.

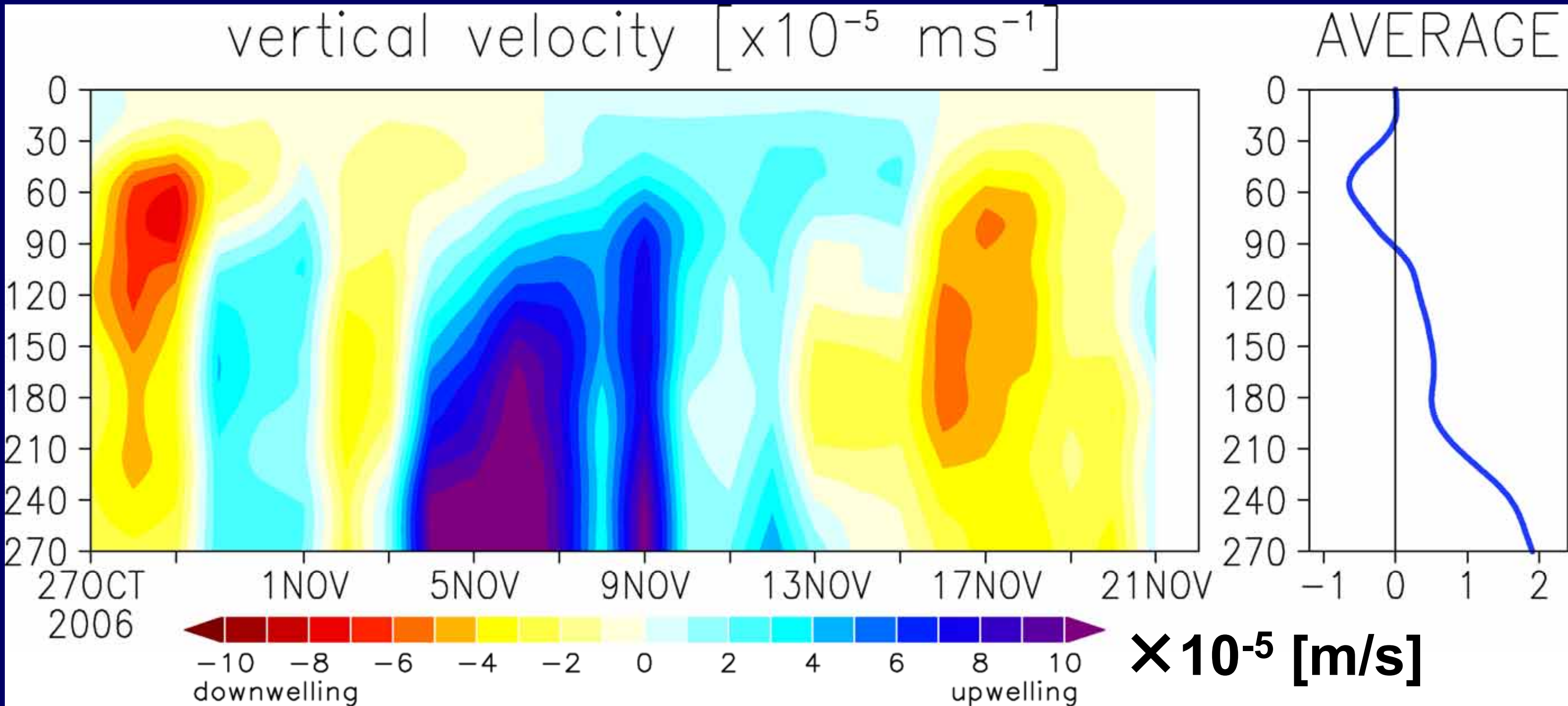
$$\frac{\partial w}{\partial z} = -\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right) \quad (1)$$

- Continuity Eq. (1)
- Integrate Eq. (1) (*w=0* at sea surface)
- Estimate Vertical Velocity



Vertical Velocity

- Intraseasonal Strong Upwelling Nov.4~9
- Amplitude > 10×10^{-5} [m/s] (10 [m/day])

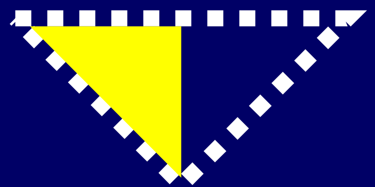


↑ Depth-Time Section of "w"

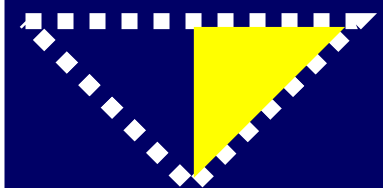
Mean of Period↑

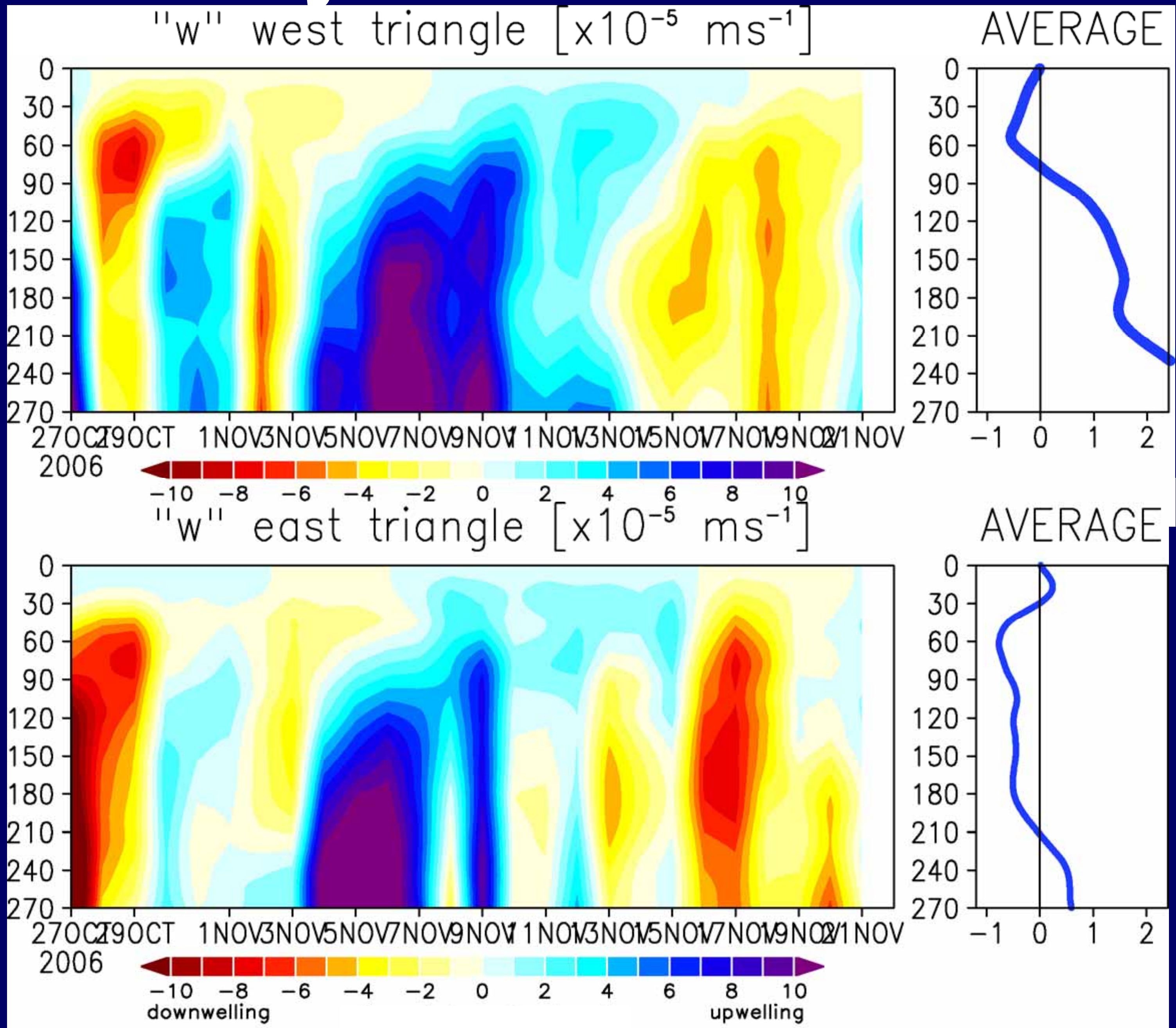
Vertical Velocity

West Region



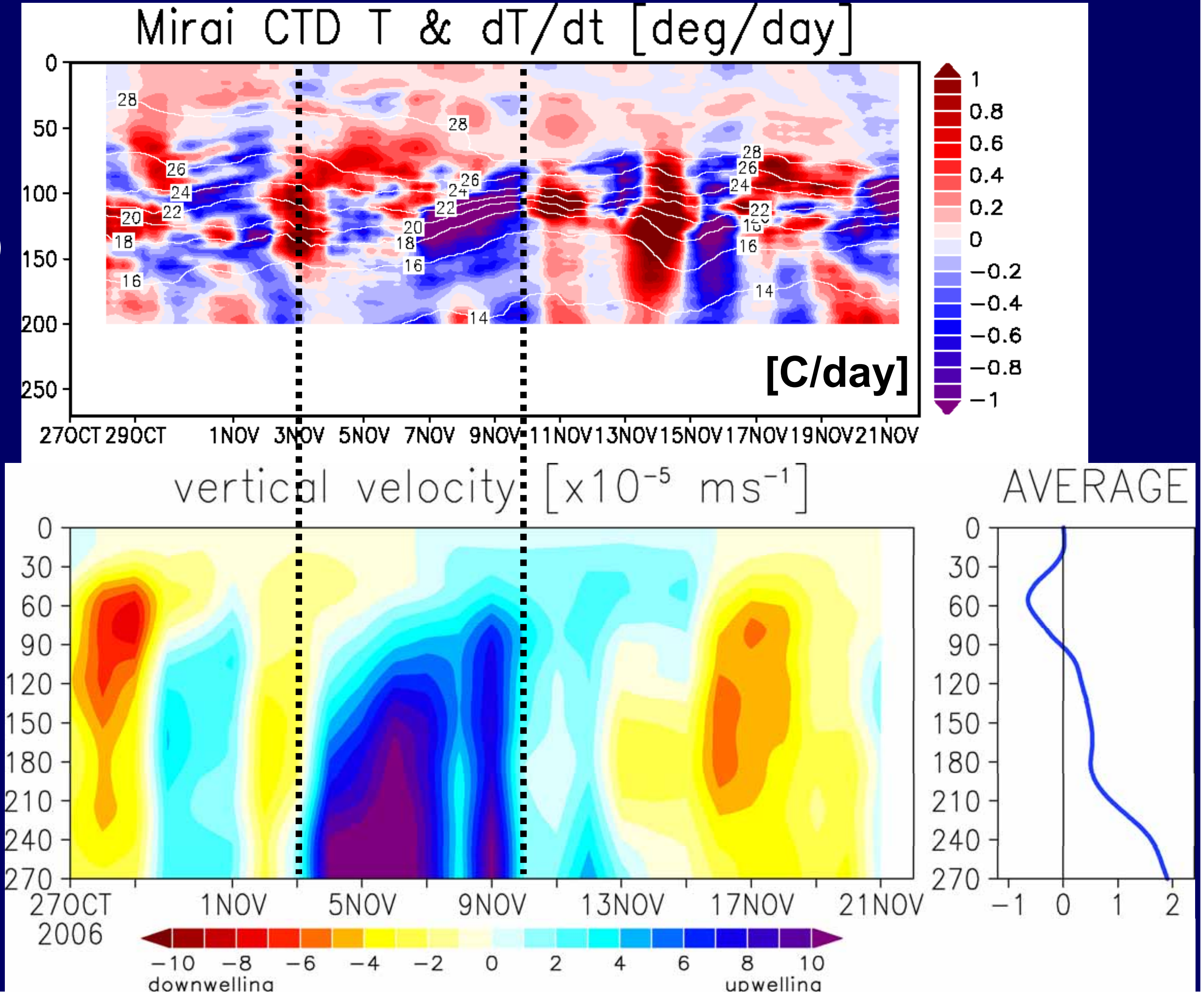
East Region





T Change (∂T/∂t) & Vertical Velocty

R/V Mirai
CTD
Measurement
(Every 3 Hour)



Summary of Part II

- Using an array of the ADCPs, Vertical Velocity "w" is estimated by the continuity equation.
  - Intraseasonal strong upwelling event below 90m
  - Large amplitude of 10×10^{-5} [m/s] (~10 [m/day])
  - Lasted about a week in the MISMO period
- The upwelling was produced by the zonal & meridional divergence.
  - Zonal current: Subsurface strong eastward current accelerated eastward
  - Meridional current：14-20day variation, suggesting mixed Rossby gravity wave
- Future:
  - Possible influences of the upwelling on the biological activity should be examined.